

REPORT DOCUMENTATION PAGE

AFRL-SR-BL-TR-01-

Public reporting burden for this collection of information is estimated to average 1 hour per response, including gathering and maintaining the data needed, and completing and reviewing the collection of information. Send collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork

0269

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE		3. REPORT	
				01 May 99 to 30 Apr 00 Final	
4. TITLE AND SUBTITLE (DURIP 99) Instrumentation to Characterize Cache-Memory Buffers & Regenerators for Optically-Digital Communication & Processing at the Quantum Limits				5. FUNDING NUMBERS 61103D 3484/US	
6. AUTHOR(S) Dr Kumar					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Northwestern University 6333 Clark Street Evanston, IL 60208				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) AFOSR/NE 801 North Randolph Street, Rm 732 Arlington, VA 22203-1977				10. SPONSORING/MONITORING AGENCY REPORT NUMBER F49620-99-1-0232	
11. SUPPLEMENTARY NOTES					
12a. DISTRIBUTION AVAILABILITY STATEMENT Approved for public release, distribution unlimited				<p>AIR FORCE OFFICE OF SCIENTIFIC RESEARCH (AFOSR) NOTICE OF TRANSMITTAL DTIC. THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR PUBLIC RELEASE LAW AFR 190-12. DISTRIBUTION IS UNLIMITED.</p>	
13. ABSTRACT (Maximum 200 words) We have used an optical parametric oscillator (OPO) to characterize the fiber-optic cache-memory buffers. Prior to addition of the new OPO system, a home-built saturable-absorber mode locked erbium/ytterbium-fiber laser had been used in all our experiments. The fiber laser delivered only 5 mW of average power, had a lower repetition rate (29 MHz), and emitted pulses at a fixed wavelength. In addition, the laser required constant tweaking because it was temperature sensitive, had unpredictable polarization dynamics, and repeatedly fell into a Q-switching mode with the slightest change of operating parameters. The time spent on constantly having to adjust the pulse source slowed the pace of the main experiments. However, with the addition of a new OPO, we are able to remedy all of the above deficiencies.					
14. SUBJECT TERMS				15. NUMBER OF PAGES	
				16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED		18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED		19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	
				20. LIMITATION OF ABSTRACT UL	

Instrumentation to Characterize Cache-Memory Buffers and Regenerators for Optically-Digital Communication and Processing at the Quantum Limit

Final Technical Report

Grant No.: F49620-99-1-0232

Period of Performance: May 1, 1999 – April 30, 2000

AFOSR Funding: \$225,000; Northwestern University Match: \$25,000

Principal Investigator: *Professor Prem Kumar*

ECE Department, Northwestern University, Evanston, IL 60208-3118

Phone: (847) 491-4128; Fax: (847) 491-4455; E-mail: kumarp@nwu.edu

With this Department of Defense University Research Instrumentation Grant, funds in the amount of \$225,000 were spent to purchase an ultrafast synchronously pumped optical parametric oscillator (OPO). The OPO, which is a tunable source of sub-picosecond pulses in the 1.3–1.5 μ m communication band, is being used to characterize novel all-optical devices, such as fiber-optic cache-memory buffers and optical regenerators, that are being developed to demonstrate optically-digital communication and processing at the quantum limit. Such devices will also be essential for deploying packet-switched ultrahigh-speed time-division multiplexed all-optical networks.

The research at Northwestern is funded through a Multidisciplinary University Research Initiative, "Integrated Devices for Tb/s 1.3 and 1.5 μ m WDM/TDM Network Applications," administered by the AFOSR [Grant No. F49620-96-1-0262; \$2,500,000 for the period 6/1/96 – 5/31/01, PI: Prem Kumar]. The aim of this project is to demonstrate novel, compact, integrated, all-optical devices for the development of >100Gb/s optical networks. Our research thrust is to develop devices that are based on parametric interactions in nonlinear media such as optical fiber and lithium-niobate waveguides. We are also studying the fundamental limits of all-optical regeneration, switching, and time recovering. We seek to quantify the optimum performance to evaluate how low can the signal be before amplification/regeneration is necessary.

In support of the graduate and undergraduate teaching activities enhanced by acquisition of this equipment, Northwestern University contributed \$25,000 of matching funds towards purchase of diagnostic instrumentation for use with the OPO (items 5–7 in the table below). As a result, the graduate students and the post-doctoral associate involved in the research program are getting better training in the technologically important field of all-optical networks. The equipment was also used to setup demonstration experiments in the course "Optics and Information Systems" that the PI taught during the winter quarter of AY99/00. Consequently, the undergraduate students were also exposed to the advances being made in the area of broadband information technology.

A detailed breakdown of the cost of the purchased instrumentation is given in the table below. The prices given are those negotiated after taking into account the university discounts. The name and phone number of the contact at the equipment vendor is also given in the table. All items are estimated to have a useful life of 5–7 years.

No.	Item	Amount
1	Mira 900-Dual Cavity Picosecond and Femtosecond Mode-locked Ti-Sapphire Laser with 110V chiller and X-wave optics	\$74,000
2	Verdi 10W pump laser with chiller	70,000
3	Mira CTA OPO with advanced diagnostics; includes both femtosecond and picosecond options	71,000
	Items 1–3, contact information: c/o Ralph Swaine, Phone (800) 400-3008, Fax (800) 362-1170; Coherent, Inc., 5100 Patrick Henry Dr., P.O. Box 54980, Santa Clara, CA 95056	
4	ESA-L 9kHz–3.0GHz spectrum analyzer, as per purchase agreement #G8M30. Includes BenchLink spectrum analyzer software, GPIB and parallel interfaces for printing, plotting and remote operation / programming.	9,652
	Contact information: c/o Stan Mills, Phone (847) 342-2392, Fax (800) 829-4433; Agilent Technologies, P.O. Box 4026, Englewood, CO 80155-4026	
5	LeCroy LT-344 4-channel 500 MHz, 500M samples/sec, 250K memory oscilloscope	9,055
	Contact information: c/o David Hurd, Phone (800) 553-2769, Fax (914) 578-5985; LeCroy, 700 Chestnut Ridge Road, Chestnut Ridge, NY 10977-6499	
6	Long range autocorrelator with custom crystal for measurements near 775nm as well as 1550 nm (cost shared with another grant)	10,115
	Contact information: c/o Arnt R. Danielsen, Phone (734) 426-2803 ext. 219, Fax (734) 426-6288; Clark-MXR, Inc., 7300 West Huron River Drive, Dexter, MI 48130	
7	Packaged semiconductor optical amplifier, Model SOA1550MRI/A	5,895
	Contact Information: c/o F. Viola, Phone 41-91-9463343, Fax 41-91-9463351; Opto Speed SA, Via Cantonale, 6805 Mezzovico, Switzerland.	
8	Shipping and Installation for Items 1–7	283
Total Discounted Cost of Instrumentation		\$250,000
Northwestern University's Contribution		\$25,000
DURIP Funds Spent		\$225,000

Originally, we proposed to purchase the OPO manufactured by Spectra-Physics, Inc. At the time of writing the grant proposal, the Spectra-Physics' OPO delivered the highest average power (over 150 mW) in a commercially available product with pulses as short as 130 femtoseconds at a 100 MHz repetition rate. However, between the time the proposal was submitted and the grant was received, Coherent, Inc., a competitor of Spectra-Physics, Inc., announced a new OPO product based on a new type of nonlinear crystal called CTA (Cesium Titanyl Phosphate). This OPO is also pumped by a mode-locked Ti-Sapphire laser, which in turn is pumped by a frequency-doubled diode-pumped Nd:YAG laser. The whole system is all solid-state and diode pumping at the back end provides very stable output pulses. The wavelength tuning is computer controlled providing easy remote-controlled turn-key operation. But, most importantly, the OPO output turned out to be shot-noise limited, which was not the case with the Spectra-Physics' OPO. Shot-noise limited performance is essential, since we seek to quantify the quantum-limited performance of all-optical regenerators and cache-memory buffers. Because of this performance advantage, and since the Coherent OPO was priced at the same level as the Spectra-Physics' OPO, we decided to purchase the former.

Impact of the Proposed Instrumentation on Research

We have used the OPO to characterize the fiber-optic cache-memory buffers. Prior to addition of the new OPO system, a home-built saturable-absorber mode locked erbium/ytterbium-fiber laser had been used in all our experiments. The fiber laser delivered only 5 mW of average power, had a lower repetition rate (29 MHz), and emitted pulses at a fixed wavelength. In addition, the laser required constant tweaking because it was very temperature sensitive, had unpredictable polarization dynamics, and repeatedly fell into a Q-switching mode with the slightest change of operating parameters. The time spent on constantly having to adjust the pulse source slowed the pace of the main experiments.

With the addition of the new OPO, we are able to remedy all of the above deficiencies. The tunability represents the main advantage of the system to our research program, since the cache-memory buffers and regenerators that we are developing can be used at any wavelength. This is because the response of the fiber-optic parametric amplifier is wavelength independent; the fiber nonlinearity, which is responsible for the gain, exists at all wavelengths and is not restricted to the relatively narrow range of the erbium band (1.53–1.56 μ m). Thus the OPO allows us to experiment in wavelength regions that have previously been inaccessible.